

## Effects of exotic tree plantations on the richness of dragonflies (Odonata) in Atlantic Forest, Rio Grande do Sul, Brazil

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One of the forest types occurring in Southern Brazil is the mixed ombrophilous forest (MOF), a subtype of the Atlantic Forest, which is one of the richest biomes on Earth. This biome currently remains as a highly fragmented mosaic, under pressure from human development. The diversity and ecology of most animal groups in this biome are poorly known. We studied Odonata in a large forest fragment, including an ecological reserve: the Floresta Nacional de São Francisco de Paula (FLONA-SFP), in Rio Grande do Sul, administrated by the Brazilian government. The reserve is dominated by MOF with sectors of *Pinus elliottii* and *Araucaria angustifolia*. Three surveys of these forest sectors over one year yielded 42 species, with the highest species richness recorded in the *P. elliottii* sector. The odonate species recorded here are all generalist in terms of habitat preferences, but they appeared only in low numbers and were very particular in their occurrence pattern. We therefore assume that the introduction of an alien element in the Atlantic Forest has given rise to a new species assemblage, where the ecology of the species is adapted to the novel habitat of *Pinus* plantations. As expected, the species occurring in the MOF sectors were mainly habitat specialists. The *Araucaria* plantations had an intermediate species composition. Despite the differences observed in habitat preference between generalist and specialist species, such exotic plantation habitats may act as a temporary biodiversity reservoir for further habitat colonization.

**Keywords:** *Araucaria*; conservation; dragonfly; ecology; generalist; *Pinus*; species composition

### Introduction

It is well known that the biodiversity of the Atlantic Forest is among the highest in the world, and one of the richest biomes that still exist (Myers, Mittermeier, Mittermeier, Fonseca, & Kent, 2000; Sick, 1982). However, this biome is now highly endangered, mainly due to the growing human population, which has resulted in fragmentation of the forest areas that formerly covered more than 15% of the total Brazilian territory. At present, less than 7% of the Atlantic Forest remains, in the form of a highly fragmented system, divided by agriculture, roads and urban zones (Goerck, 1997; Tabarelli, Aguiar, Ribeiro, Metzger, & Peres, 2010). In southern Brazil, the reduction of the forest area seems inevitable due to the constant expansion of agriculture and cattle farming, and this constitutes one of the largest conservation challenges ever faced (Backes, 2001). Amongst the forest biomes occurring in the Rio Grande do Sul state is a subtype of the Atlantic Forest biome: the mixed ombrophilous forest (MOF), which covers the northern

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and north-eastern portions of the state. The Austral-Andine and Afro-Brazilian origin of this vegetation renders it the typical composition of a montane rain forest, and it is characterized by the occurrence of *Araucaria angustifolia* (Bertol.) Kuntze (Araucariaceae), commonly known as Paraná-Pine or Brazilian pine (Veloso, Rangel Filho, & Lima, 1991), a critically endangered species (Thomas, 2013). The occurrence of *A. angustifolia* features a typical vegetational structure pattern in the understorey and canopy of this forest type, as the higher trees constitute a stable cover for the lower vegetation. The forest canopy is mainly composed of deciduous trees of the families Lauraceae, Sapindaceae and Aquifoliaceae, comprising 60–70% of the tree cover, with the *A. angustifolia* tops emerging from it. The understorey is mainly composed of species belonging to the families Myrtaceae, Podocarpaceae and Leguminosae (Quadros & Pata Pillar, 2002). The high quality of the Paraná-pine wood has led to overexploitation and logging of the species for timber (Hueck, 1972), despite its global rarity. Today the remainder of the MOF is highly fragmented, and the largest fragments are found in conservation areas such as the Floresta Nacional de São Francisco de Paula (FLONA-SFP) – a sustainable ecological reserve, controlled by the Brazilian Ministry of Environment. These forest reserves are managed according to sustainable practices, including management of planted forest areas of alien *Pinus elliottii* Engelm. and *A. angustifolia*, which generate financial resources for the maintenance of the conservation units.

Efforts to preserve the Atlantic Forest fragments are hampered by the paucity of information, and this is especially true of the scattered aquatic habitats forming part of the forest mosaic. Looking at dragonflies, there are many reports of forests and their structures being central to the formation of diverse dragonfly assemblages (Sahlén, 2006), especially in temperate forests. Dragonflies respond quickly to human disturbance, are known to indicate general species richness, and have been used as tools when monitoring recovery of restored habitats (e.g. Clausnitzer, 2003; Monteiro Júnior, Juen, & Hamada, 2014; Oertli, 2008; Sahlén & Ekestubbe, 2001). Zygopterans are reported to be more affected by local environmental changes than anisopterans, due to their assumed lower dispersal abilities (Corbet, 1999; Monteiro Júnior et al., 2014). Hence, the presence/absence and composition of odonate species belonging to both suborders can reflect human activity in the body of water, its immediate surroundings, and in adjacent forest zones (Koch, Wagner, & Sahlén, 2014; Rith-Najarian, 1998; Sahlén, 1999, 2006), including changes in the structure of the forest studied. A typical Brazilian example of this was demonstrated by Machado (2001), where species with a wide geographical range were predominant in open savannah vegetation, while those with a more restricted distribution dominated in forested habitats.

In the FLONA-SFP, we aimed to investigate if the aquatic habitats in original areas of MOF contain unique species assemblages of dragonflies and, if so, how much of this species assemblage has remained in the sustainably planted forest areas of *P. elliottii* and *A. angustifolia*. We also investigated if species occurring only in the foreign *P. elliottii* plantations are commonly established in the area, and what impact they may have on the overall species composition. To investigate this we surveyed the Odonata in 26 aquatic habitats in the three different types of vegetation available in the FLONA-SFP. The MOF is on the brink of disappearing in Rio Grande do Sul, and knowledge of species which might still be strongly associated with these rare forest areas might help in designing future conservation measures for the Atlantic Forest biome as a whole.

## Sites, materials and methods

### Fieldwork

We sampled adult dragonflies in 26 aquatic habitats within the FLONA-SFP, a conservation unit at 29.422° S, 50.386° W (Figure 1), in the upper part of the Sinos River basin. The area is admin-

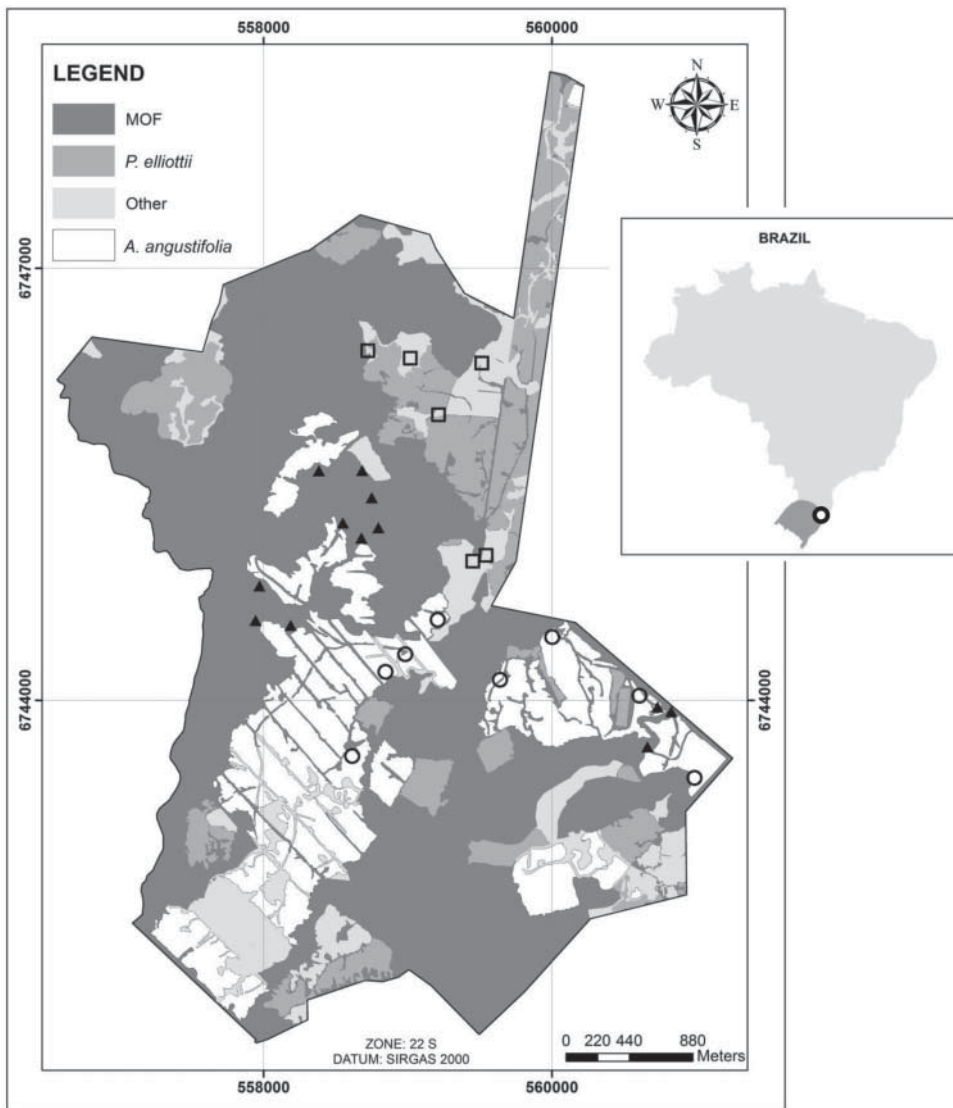


Figure 1. Map of Brazil with Rio Grande do Sul state highlighted and detail of FLONA-SFP with the 26 sampling localities and vegetation sectors: MOF dark grey with localities as solid triangles; *A. angustifolia* white with open circles; *P. elliottii* light grey with open squares.

istered by Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio) a division of the Brazilian Ministry of Environment. The area consists of 1572 ha forest, 720 ha of which is covered with native MOF. The other sectors are composed of sustainably managed tree plantations – *Araucaria* (69 ha), *Pinus* (204 ha) – and a few scattered, open fields (20 ha). The elevation varies from 900 to 1000 m asl, and the climate is mesothermic humid (Cfb Köppen), with a mean temperature of 14.5°C and a mean precipitation above 2000 mm annually. Below-zero temperatures may occur from April to November, with snow and ice formation during cold winters (INPE, 2014). All sites were small, up to 100 m in length or diameter with an area ranging from some 100 m<sup>2</sup> up to 0.8 ha. They differed in a gradient from rapid running rivulets/small rivers via seeping water to standing water similar to ponds.

All the sampling sites were visited during three seasons: summer (2–9 January 2014), autumn (10–16 May 2014) and spring (2–8 November 2014). No sampling was conducted during the winter season. Flying odonates were caught with insect nets during sunny days from 09:00 to 16:00 h in proximity of the water. Sampling was done by two persons walking the edge and surroundings of the waterbodies, up to 10 m from the edge of the water. We collected or noted the occurring species until no new species were encountered for approximately 10 min (qualitative sampling); an average time of 90 min was spent sampling at each site.

All collected specimens were preserved in 96% ethanol and later identified to species level according to Garrison, von Ellenrieder and Louton (2006, 2010), Heckman (2006, 2010) and Lencioni (2006). The systematics follows Dijkstra et al. (2013) and Dijkstra, Kalkman, Dow, Stokvis, and van Tol (2014). All voucher specimens were deposited in the Invertebrate Collection of the Univas Natural History Museum (MCNU) in Lajeado, RS. The collection authorization process was issued by IBAMA, through SISBio system under the number 38928-1.

This paper is based on a part of a bigger dataset from FLONA-SFP and immediate surroundings. The whole dataset has previously been used in other publications, namely a check list of species occurring in the region (Renner, Périco, & Sahlén, 2016).

### Comparison of Odonata assemblages

We analysed whether the average total species, as well as the number of species within the suborders Zygoptera and Anisoptera, differed between the vegetation types occurring in the three sectors of the conservation unit. The number of sites within each sector was dependent on the sector area, as can be seen in Figure 1. In each sector we included standing, seeping and running water among our sites:

- pristine MOF ( $N = 12$ ); undisturbed, original forest, remarkable by the presence of 200+ years old *A. angustifolia*, understorey composed mainly of old deciduous trees (Myrtaceae, Podocarpaceae and Leguminosae) distributed in heterogenic patterns;
- planted *A. angustifolia* ( $N = 8$ ), trees aligned in rows, most of them planted in the 1950s, the understorey component consisting mostly of smaller trees and bushes of the same species that were encountered in the native MOF, with sparse (varying) amount of native riparian vegetation;
- regular rows of *P. elliottii* ( $N = 6$ ), planted in 1991. Understorey composed of only pine leaf litter, with no native riparian vegetation.

We used a matrix of presence/absence data compiled from all three sampling occasions to verify the spatial distribution of the species in relation to the three vegetation types, using non-metric multidimensional scaling (NMDS) through the software Past v3.06 (Hammer, 2015; the algorithm was based on Taguchi & Oono, 2005). The measure of similarity employed was Euclidian distances measuring the precision degree by the stress, in which values below 0.2 are considered acceptable and values below 0.1 excellent, denoting “no interference” in the ordination (Clarke, 1993). This analysis groups the localities based on their species composition, indicating if the surrounding vegetation is a good separator for specific species assemblages.

As total sampling time differed between sites we tested the effectiveness of our sampling efforts for each vegetation type, building rarefaction curves using the software Estimates 9.1.0 (Colwell, 2009). As each site was visited three times (in different seasons) we had 18 sampling events in the *P. elliottii* area, 24 in the *A. angustifolia*, and 36 in the MOF. The resulting curve was extrapolated from 78 samples, with 1000 repetitions.

In the next step we compared the occurrence of species between the three vegetation types, noting unique and shared species. A species may occur in 1–3 different types of vegetation.

These groups were subsequently discussed, taking into account rarity, ecology and conservation issues.

## Results

We were able to identify 38 species. Another four species were determined to genus level, as we found only female specimens or no up-to-date key exists. We hence identified 42 taxa (21 Zygoptera, 21 Anisoptera) representing seven families: Calopterygidae, Coenagrionidae, Lestidae, Heteragrionidae, Aeshnidae, Gomphidae and Libellulidae. The dominant families were Coenagrionidae and Libellulidae, with 13 and 14 species, respectively.

In the MOF sectors we encountered 22 species with an average of  $4.83 \pm 2.21$  (SD) per site. The same number of species (22) was also found in the *A. angustifolia* plantations ( $6.50 \pm 4.69$  per site). The *P. elliottii* plantations had a slightly higher species number, 27, and the highest average ( $13.5 \pm 4.72$ ).

The three sectors differed a lot in species composition, with only seven species (16.7%) encountered in all three forest types (Figure 2). The number of species found only in one sector was also low, ranging from four (in *A. angustifolia* plantations) to seven (in MOF) and nine (in *P. elliottii* plantations; Figure 2). The *P. elliottii* plantations had the highest number of such species per site (1.5) compared to a low number per site in MOF (0.58) and *A. angustifolia* plantations (0.5). The sector specific contribution of the six sites in *P. elliottii* plantations accounted for more than one fifth (21.4%) of the total species pool. The rarefaction curves obtained through extrapolation showed the effectiveness of our sampling effort: we caught 91.6% of the expected species for *A. angustifolia*, 79.4%, for *P. elliottii* and 88% for MOF (Figure 3), suggesting that the *P. elliottii* areas are the least well sampled, albeit having the highest observed species number.

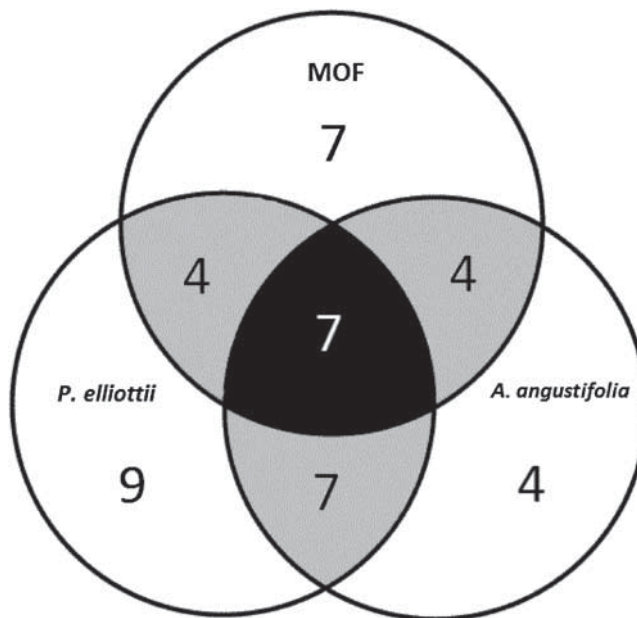


Figure 2. Venn diagram of absolute contribution to regional diversity (42 species) made up of the three vegetation types MOF, *A. angustifolia* plantations and *P. elliottii* plantations (12, eight and six sampled sites, respectively). Numbers in shaded areas indicate species shared by vegetation types: black, triple overlap; grey, double overlap. Numbers in white areas indicate species specific to a single type of vegetation.

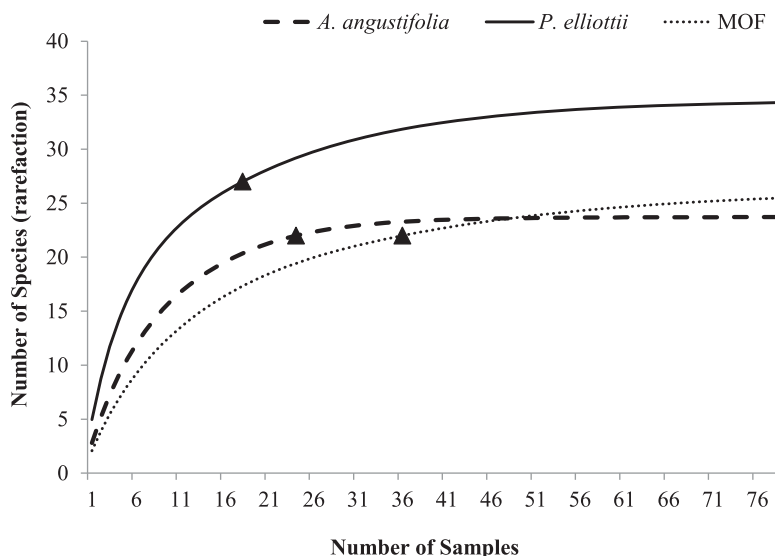


Figure 3. Rarefaction curves for the three vegetation types: *A. angustifolia*, *P. elliottii* and MOF. The triangles showing the total sampling effort for each vegetation type.

The species occurring in all sectors were members of three genera. These were *Oxyagrion terminale* Selys, 1876 and one unidentified *Oxyagrion* species, *Rhionaeschna bonariensis* Rambur, 1842, *R. planaltica* Calvert, 1952 and *Erythrodiplax hyalina* Förster, 1907, *E. media* Borror, 1942 and another unidentified *Erythrodiplax* species. A modest number of species occurred in two types of vegetation, with four species occurring in MOF and *A. angustifolia* plantations and likewise four in MOF and *P. elliottii* plantations, but there were seven species common to both *A. angustifolia* and *P. elliottii* plantations (Figure 2).

The NMDS analysis of species occurrence in the three vegetation sectors showed a clear separation between the species assemblages in the pristine MOF and the planted *P. elliottii* areas (Figure 4). The species assemblage found in *A. angustifolia* plantations was intermediate, including species typical of both of the other sectors. The stress level found in this analysis was 0.1695 ( $< 0.2$ ), i.e. ‘good’ by the Clarke index (Clarke, 1993), indicating low interference in the analysis.

## Discussion

In the native MOF areas of the conservation unit FLONA-SFP, only a limited number of species existed, in our case 22 out of 42 species (52%), with seven unique species (16.7% of the species pool). Instead, the greatest contribution to the regional species richness came from the plantations of the North American *P. elliottii*, in which 27 species (64%) were encountered, nine of which (21.4%) were unique to the sector. In planted *A. angustifolia* areas, the number was again lower (22) with four unique species. Hence, the pattern observed for the amphibiotic Odonata differs from that of many terrestrial groups: Fonseca et al. (2009), working in FLONA-SFP with other groups of invertebrates, showed that with few exceptions, the monocultures of *A. angustifolia* and *P. elliottii* harboured just over half of the *Araucaria* Forest (MOF) species; whereas we recorded a higher percentage. In the case of Odonata, Machado (2001) showed that many species with a wide geographical range (widespread and common species) were more abundant in open savannah vegetation, while the rarer species dominated in forest habitats. It is also well



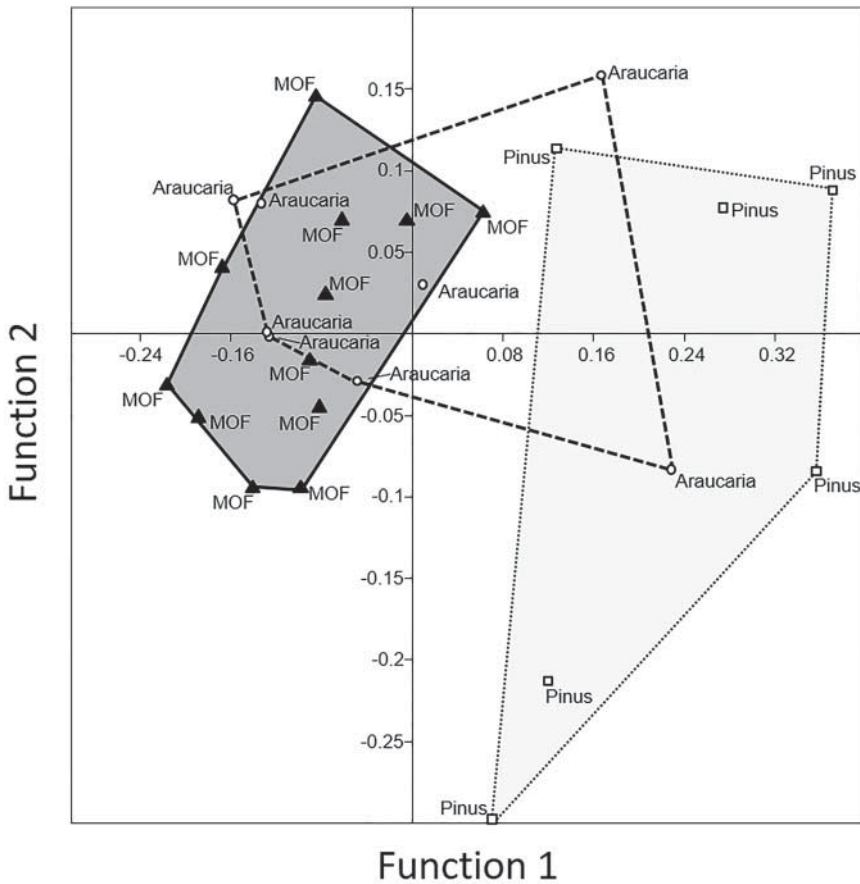


Figure 4. NMDS plot based on species occurrence in aquatic habitats within the three different types of vegetation (MOF, *A. angustifolia* and *P. elliottii*) in FLONA-SFP. All MOF habitats are in a dense aggregation, indicating a somewhat similar species composition. The *A. angustifolia* plantations include species typical of both MOF and *P. elliottii* plantations, the latter very scattered, indicating a more heterogeneous species composition.

known (e.g. Stewart & Samways, 1998; Samways & Steytler, 1995) that Odonata assemblages in disturbed habitats will often consist of many widespread generalist species. We therefore assume that there is an ‘opportunistic’ species pool with good dispersers available for rapid colonization of water bodies in man-made habitats, including the plantations of *P. elliottii* sampled here. These sectors have a slightly higher number of species, where each site is adding no less than 1.5 sector specific species to the regional species pool, a high number (cf. Thiere et al., 2009 for wetlands in north temperate regions), three times higher than in the other two sectors sampled here.

It is well known that humans alter habitats and ecosystems, and in the case of Odonata this invariably results in a changed species composition (e.g. Brasil, da Silva, & Almeida, 2014; Dolný, Bárta, Lhota, & Drozd, 2011). It is important to understand what kind of species composition will develop in the changed habitat, and the processes behind these assemblage shifts. Dolný et al. (2011) showed for Borneo that forest degradation results in fewer species, a change in species composition, and a reduction in taxonomic diversity. Juen, Oliveira Junior, Shimano, Mendes and Cabette (2014) showed that anisopterans will dominate in forest clearings. This is, however, not the case here – instead the number of species belonging to the two suborders is similar. One difference is that we are dealing with mature tree plantations with a developed canopy

Table 1. Sector specific species encountered in the three vegetation zones of FLONA-SFP, with number of specimens encountered and number of sites where it occurred within brackets.

Species	MOF	<i>A. angustifolia</i>	<i>P. Elliottii</i>
<i>Argentagrion ambiguum</i> Ris, 1904	–	4(1)	–
<i>Argia</i> sp.	1(1)	–	–
<i>Dasythemis mincki mincki</i> Karsch, 1890	–	1(1)	–
<i>Erythrodiplax atroterminata</i> Ris, 1911	1(1)	–	–
<i>Heteragrion luizfelipei</i> Machado, 2006	4(4)	–	–
<i>Ischnura</i> sp.	–	1(1)	–
<i>Lestes auritus</i> (Hagen in Selys, 1862)	–	–	4(2)
<i>Lestes paulistus</i> Calvert, 1909	–	–	2(2)
<i>Lestes pictus</i> (Hagen in Selys, 1862)	–	–	2(1)
<i>Libellula herculea</i> Karsch, 1889	–	–	1(1)
<i>Limnometra debile</i> Karsch, 1891	3(3)	–	–
<i>Macrothemis marmorata</i> Hagen, 1868	–	1(1)	–
<i>Micrathyria artemis</i> Ris, 1911	1(1)	–	–
<i>Mnesarete pruinosa</i> (Hagen in Selys, 1862)	5(2)	–	–
<i>Orthemis discolor</i> Burmeister, 1839	–	–	1(1)
<i>Oxyagrion microstigma</i> Selys, 1876	–	–	4(2)
<i>Perithemis icteroptera</i> (Selys in Sagra, 1857)	–	–	3(2)
<i>Perithemis mooma</i> Kirby, 1889	–	–	1(1)
<i>Phyllogomphoides regularis</i> Selys, 1873	3(2)	–	–
<i>Telebasis theodori</i> Navás, 1934	–	–	8(3)
Total number of unique species	7	4	9

providing shade. The species composition is still different from that of the MOF, with predominance of generalist species, and with almost an equal number of zygopterans and anisopterans (cf. Monteiro Júnior, Couceiro, Hamada, & Juen, 2013). A mature, altered forest might therefore have a species composition that is seemingly similar to that of a pristine forest but yet differing in both quality and composition, something shown previously both in arid areas in southern Africa (Suhling, Sahlén, Martens, Marais, & Schütte, 2006) and in temperate Europe (Koch et al., 2014; Sahlén, 1999; Sahlén & Ekestubbe, 2001). We can therefore confirm the findings by Monteiro Júnior et al. (2014), who argue that general species richness is a potentially misleading parameter when analysing preserved and degraded environments, since it is known that assemblages of Odonata can sometimes increase with human disturbance. The highest diversity of Odonata in the Atlantic Forest of FLONA-SFP is seemingly not found in pristine habitats but in anthropogenically altered ones. This fact is also corroborated by the estimated total richness in which the *P. elliottii* sectors were found to be even richer than the other two other types of vegetation. Based on the rarefaction curves, we caught 79,4% of the expected species for the area, although the sampling time was smaller than the other areas.

It is known that compositional heterogeneity is a key feature supporting high regional species richness in small bodies of water (Scheffer et al., 2006). The differences between individual sampling sites in our study were large, as shown by the high standard deviation, especially in the *A. angustifolia* and *P. elliottii* sectors. The variation between the sites in the MOF sector was considerably smaller. Múrria, Rugenski, Whiles and Vogler (2015), working in Panama, showed that the dispersal of aquatic insects between streams was limited, resulting in local assemblages with high endemism. Although endemism is not an issue in our study, looking more closely at the species unique to the MOF and the *P. elliottii* sectors (Table 1) might yield a pattern of their habitat choice and their opportunities for dispersal.

All seven species unique to the MOF belong to different genera; some with many, others with but a few known species (Garrison et al., 2006). *Argia* is a large genus in need of revision (Garrison et al., 2010). For most of the tropical species, the ecological information is very scanty (Caesar, 2012), but at least in the northern Neotropics and southern North America many



species are endemic or rare. Species of *Argia* are known to occur in the Atlantic Forest, preferring pool litter as substrate (Buss, Baptista, Nessimian, & Egler, 2004). *Heteragrion luizfelipei* Machado, 2006 was recently described (Machado, 2006) from Joinville and Urubuci in Santa Catarina, the neighbouring state to Rio Grande do Sul. Nothing is known of the ecology of the species, but in our study it was found in shaded, dense forest near a slow flowing stream (c.0.5–1 m wide) with boulder/gravel bottom. *Mnesarete pruinosa* (Hagen in Selys, 1853) is also a species with unknown ecology, but a sister species, *Mnesarete borchgravii* Selys, 1869 has been reported to inhabit a forest stream between a nature reserve (Pró-Mata – PUCRS) and farmland (Kittel & Engels, 2014) in RS. Both species were found near streams, but *M. pruinosa* seemed to prefer relatively large clearings in the forest canopy, while *M. borchgravii* occurred also in shaded areas or in small sun flecks. *Limnetron debile* Karsch, 1891 is reported to be a typical forest species, inhabiting mountain streams of primary Atlantic Forest, and its larval development and habitat has been described in detail (Assis, Cravalho, & Dorvillé, 2000). The occurrence of *Phyllogomphoides regularis* Selys, 1873 in the MOF is not unexpected, since gomphids can be numerous in some forested habitats, as shown e.g. by Almeida, Pinto, Carvalho, and Takiya (2013). *Micrathyria artemis* Ris, 1911 is reported to inhabit original growth areas in São Paulo State, Brazil (Ferreira-Peruquetti & Fonseca-Gessner, 2003). The ecology of *Erythrodiplax atroterminata* Ris, 1911 is relatively unknown, but it occurs along with other habitat specialists in fragmented forests in southern Brazil (Renner, Sahlén, & Périco, 2016).

As the last four species above are all anisopterans, and therefore normally good flyers/dispersers (Corbet, 1999; Monteiro Júnior et al., 2014), their occurrences in the MOF might be related to the proximity of edge areas between the MOF and other vegetation sectors. But as they were not encountered elsewhere, their occurrence may be due to environmental conditions, biotic and abiotic structures, a well-known pattern for forest dwelling species (Sahlén, 2006).

In the planted *P. elliottii* areas we can see another pattern: most species unique to this sector are known to be generalists, e.g. species of the genera *Erythrodiplax* (Anisoptera), *Acanthagrion*, *Oxyagrion* and *Ischnura* (Zygoptera). Many members of these genera are reported to occur primarily in open areas over large parts of the Neotropics (Machado, 2001; Monteiro Júnior et al., 2014). In our study they occur at sites which are not open; most sites had rich and diverse emergent and floating aquatic vegetation and structural components such as remains of dead *Pinus* and other dry wood. It is known that habitat structures are of greater importance in forested environments than in the open (Koch et al., 2014). In forest environments such structural elements are among the key factors regulating the occurrence of Odonata (Sahlén, 2006), and having a very high impact on a regional scale (Jeanmougin, Leprieur, Lois, & Clergeau, 2014). We should note that the presence of generalist species may be detrimental to the original, local species assemblages, since they tend to affect the colonization-extinction dynamics of original and disturbed environments, as demonstrated by De Marco and Resende (2004). Samways (2003) pointed out that human impact might not diminish dragonfly diversity but rather trigger a change in the species assemblage, where rare (endemic) species were replaced by habitat-tolerant and highly mobile species. This fits the pattern we have observed here. Further, Smith, Samways, and Taylor (2007) showed that odonate species were more sensitive to vegetation structure than composition, and in riparian areas, open versus closed canopy accounted for more variation than native versus exotic tree species. Part of the variation we observe might therefore be due to the different (denser) structure of the *P. elliottii* canopies.

Dragonflies are affected by all kinds of human disturbance, e.g. urbanization (Jeanmougin et al., 2014), forestry (Sahlén, 1999) and agriculture (Koch et al., 2014) as well as other types of ecosystem drivers like the presence of fish (Wittwer, Sahlén, & Suhling, 2010). The effect is always a change in species composition. But in a forest environment, the regional species pool in areas surrounding the study sites may reduce the extinction and turnover rates and have a positive effect on changes in species composition, i.e. enable a higher number of species to

co-exist than in open areas (Koch et al., 2014). We observed that the abundance of the sector specific species was generally low, often only single specimens seen at each collecting site over the year (Table 1). There may be two explanations for this: First, the species might be vagrants, appearing at the sites randomly, which would explain the single specimens. Further, vagrants would be more easy to observe in open vegetation (MOF and *A. angustifolia* plantations) than in dense vegetation (*Pinus elliotii* plantations) and therefore more such undetected species may be expected from the area. However, dragonfly species utilize shoreline vegetation in many different ways by varying behaviour and using cryptic coloration (Butler & deMaynadier, 2008; Dolný, Harabiš, & Mižičova, 2014). Open vegetation might therefore not mean that species are easier to detect. Odonates are good dispersers, and reports of the occurrence of vagrants are common; especially on peninsulas (e.g. Dumont, Haritonov, Kosterin, Malikova, & Popova, 2005), but also in forests and arid areas (Sahlén, 1999; Suhling et al., 2006). A problem with this interpretation is that vagrants should appear as a ‘noise’ in the dataset, i.e. randomly, which they do not in this case. Second, these species might be rare in the area, regardless of which sector they appear in, and that, if we speculate a bit, would have interesting implications. We know that vegetation structure might be a good indicator of habitat requirements of generalist predators, such as dragonflies (Remsburg & Turner, 2009), while landscape connectivity depends on the abundance and spatial patterning of habitat patches, linked to the habitat specificity and dispersal abilities of species (Henle, Davies, Kleyer, Margules, & Settele, 2004; With & Crist, 1995). It can be assumed that habitat specialists with limited dispersal ability find it harder to survive in a fragmented landscape than species with a high dispersal ability. We would therefore expect greater species richness in larger patches (cf. Debinski & Holt, 2000), but edge effects and competition may alter the response of certain organism groups, e.g. generalist predators like the Odonata. Bender, Contreras and Fahrig (1998) noted that for species occurring in an edge habitat, the population decline would be smaller than expected by habitat loss alone, and that migratory species would decline less than resident species. It is also known that specialist species have lower local extinction rates than generalist species, since generalist species occur in both low- and high-quality habitats, as shown by Suhonen, Korkeamäki, Salmela, and Kuitunen (2014). It is therefore not surprising that unique species occur in low numbers in all the surveyed sectors. They might be rare specialist species or rare generalist species occurring in an edge habitat. The problem with this interpretation is that we are not looking at forest patches *per se*, as our entire forest is a large, coherent section, i.e. more of a core area (Ribeiro, Metzger, Martensen, Ponzoni, & Hirota, 2009). Many environmental changes and ecological processes contribute to both accumulation and decline of biodiversity, meaning that many environmental changes, even those associated with the habitat degradation, can lead to a rise in species richness (Sheil, 1999). We may also mention the issues of light/shade availability for thermoregulation in species patrolling or perching at the sites (May, 1976) and the amount of food available for larvae; the amount possibly lower in a *Pinus* plantation where the decomposer food chain only has pine needles as substrate. We have also observed that the type of water body influences the species composition in this area (Renner, Sahlén, & Périco, 2016) but we would have needed to include a much larger number of sampling sites in our study to evaluate this factor in relation to the impact of the vegetation as discussed here.

As shown in Figure 4, the species composition in the *P. elliotii* sector is distinctive and clearly differing from that of the MOF. Thus, by adding a non-native component to the Atlantic Forest, conditions for a totally new species pool has been created in the water bodies of this sector. This is the same pattern as that reported from arid areas in Namibia, where river impoundments forming lakes in a lake-less landscape have attracted a variety of stagnant water and river species, creating a distinct species pool not seen elsewhere in the country (Suhling et al., 2006). In several studies in southern Africa the normal pattern seen has been that the introduction of exotic trees has led to a general decrease in the number of species, especially rare and endemic ones (e.g. Samways

& Sharratt, 2010; Samways & Taylor, 2004). In our case, the new assemblages appearing in exotic tree plantations in Atlantic Forest in southern Brazil includes both generalist and specialist species, some of the latter with a very small area of occurrence.

We observed habitat preference between generalist and specialist species, such exotic forest habitats like pine plantations may act as a temporary biodiversity reservoir for further habitat colonization. Thus, preservation of the Atlantic Forest and the high biodiversity therein requires some thought. Introduced alien components will change the species composition in the modified parts of the forest and these, in turn, will influence the diversity as a whole. A pristine ecosystem does not necessarily harbour a higher number of species than a degraded one and, likewise, a degraded system may include habitat specialists as well as generalists. Currently no red list exists for the species in this area. We hope that surveys such as ours may serve as a basis for ongoing and future conservation assessments. Further studies to evaluate which factors are most important to Atlantic Forest aquatic diversity are recommended.

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## References

- Almeida, M. V. O., Pinto, A. P., Carvalho, A. L., & Takiya, D. M., (2013). When rare is just a matter of sampling: Unexpected dominance of clubtail dragonflies (Odonata, Gomphidae) through different collecting methods at Parque Nacional da Serra do Cipó, Minas Gerais State, Brazil. *Revista Brasileira de Entomologia*, 57, 417–423. doi:10.1590/S0085-56262013005000042
- Assis, J., Carvalho, A., & Dorvillé, L. (2000). Aspects of larval development of *Limnietron debile* (Karsch) in a mountain stream of Rio de Janeiro state, Brazil (Anisoptera: Aeshnidae). *Odonatologica*, 29, 151–155.
- Backes, A. (2001). Determinação da idade e regeneração natural de uma população de *Araucaria angustifolia* (Bertol.) Kuntze em um povoamento florestal localizado no município de Caxias do Sul, RS, Brasil. *Iheringia Série Botânica*, 56, 115–130.
- Bender, D. J., Contreras, T. A., & Fahrig, L. (1998). Habitat loss and population decline: A meta-analysis of the patch size effect. *Ecology*, 79, 517–533. doi:10.1890/0012-9658(1998)079[0517:HLAPDA]2.0.CO;2
- Brasil, L. S., da Silva, G. N. F., & Almeida, S. M. (2014). Does the damming of streams in the southern Amazon basin affect dragonfly and damselfly assemblages (Odonata: Insecta)? A preliminary study. *International Journal of Odonatology*, 17, 187–197. doi:10.1080/13887890.2014.963712
- Buss, D. F., Baptista, D. F., Nessimian, J. L., & Egler, M. (2004). Substrate specificity, environmental degradation and disturbance structuring macroinvertebrate assemblages in neotropical streams. *Hydrobiologia*, 518, 179–188. doi:10.1023/B:HYDR.0000025067.66126.1c
- Butler, R. G., & deMaynadier, P. G. (2008). The significance of littoral and shoreline habitat integrity to the conservation of lacustrine damselflies (Odonata). *Journal of Insect Conservation*, 12, 23–36. doi:10.1007/s10841-006-9059-0
- Caesar, R. M. (2012). *Phylogeny of the genus Argia (Odonata: Coenagrionidae) with emphasis on evolution*. PhD Dissertation, The Ohio State University, Ohio.
- Clarke, K. R. (1993). Non-parametric multivariate analyses of changes in community structure. *Australian Journal of Ecology*, 18, 117–143. doi:10.1111/j.1442-9993.1993.tb00438.x
- Clausnitzer, V. (2003). Dragonfly communities in coastal habitats of Kenya: Indication of biotope quality and the need of conservation measures. *Biodiversity and Conservation*, 12, 333–356. doi:10.1023/A:1021920402913
- Colwell, R. K. (2009). *Estimates: Statistical estimation of species richness and shared species from samples, version 6.0 b1: User's guide and application*. Storrs, CT: University of Connecticut. Retrieved from <http://viceroy.eeb.uconn.edu/estimates2009>
- Corbet, P. S. (1999). *Dragonflies: Behavior and ecology of Odonata*. Ithaca, NY: Cornell University Press.
- Debinski, D. M., & Holt, R. D. (2000). A survey and overview of habitat fragmentation experiments. *Conservation Biology*, 14, 342–355. doi:10.1046/j.1523-1739.2000.98081.x
- De Marco, P., & Resende, D. (2004). Cues for territory choice in two tropical dragonflies. *Neotropical Entomology*, 33, 397–401. doi:10.1590/S1519-566X2004000400001
- Dijkstra, K.-D. B., Bechly, G., Bybee, S. M., Dow, R. A., Dumont, H. J., Fleck, G., Ware, J. (2013). The classification and diversity of dragonflies and damselflies (Odonata). In Z.-Q. Zhang (Ed.), *Animal biodiversity: An outline of*

- higher-level classification and survey of taxonomic richness (addenda 2013) (pp. 36–45). *Zootaxa*, 3703, 1–82. doi:10.11646/zootaxa.3703.1.9
- Dijkstra, K.-D. B., Kalkman, V. J., Dow, R. A., Stokvis, F. R., & van Tol, J. (2014). Redefining the damselfly families: A comprehensive molecular phylogeny of Zygoptera (Odonata). *Systematic Entomology*, 39, 68–96. doi:10.1111/syen.12035
- Dolný, A., Bárta, D., Lhota, S., & Drozd, P. (2011). Dragonflies (Odonata) in the Bornean rain forest as indicators of changes in biodiversity resulting from forest modification and destruction. *Tropical Zoology*, 24, 63–86.
- Dolný, A., Harabiš, F., & Mižičova, H. (2014). Home range, movement, and distribution patterns of the threatened dragonfly *Sympetrum depressiusculum* (Odonata: Libellulidae): A thousand times greater territory to protect? *PLoS One*, 9(7), e100408. doi:10.1371/journal.pone.0100408
- Dumont, H. J., Haritonov, A. Y., Kosterin, O. E., Malikova, E. I., & Popova, O. (2005). A review of the Odonata of Kamchatka Peninsula, Russia. *Odonatologica*, 34, 131–153. Retrieved from <http://hdl.handle.net/1854/LU-342239>
- Ferreira-Peruquetti, P. S., & Fonseca-Gessner, A. A. (2003). Comunidade de Odonata (Insecta) em áreas naturais de Cerrado e monocultura no nordeste do Estado de São Paulo, Brasil: relação entre o uso do solo e a riqueza faunística. *Revista Brasileira de Zoologia*, 20, 219–224. doi:10.1590/S0101-81752003000200008
- Fonseca, C. R., Ganade, G., Baldissera, R., Becker, C. G., Boelter, C. R., Brescovit, A. D., Vieira, E. M. (2009). Towards an ecologically-sustainable forestry in the Atlantic Forest. *Biological Conservation*, 142, 1209–1219. doi:10.1016/j.biocon.2009.02.017
- Garrison, R. W., von Ellenrieder, N., & Louton, J. A. (2006). *Dragonfly genera of the new world: An illustrated and annotated key to the Zygoptera*. Baltimore, MA: The John Hopkins University Press.
- Garrison, R. W., von Ellenrieder, N., & Louton, J. A. (2010). *Damselfly genera of the new world: An illustrated and annotated key to the Zygoptera*. Baltimore, MA: The John Hopkins University Press.
- Goerck, J. M. (1997) Patterns of rarity in the birds of the Atlantic Forest of Brazil. *Conservation Biology*, 11, 112–118.
- Hammer, Ø. (2015). *PAST, PAleontological STatistics, Version 3.06*. Natural History Museum, University of Oslo.
- Heckman, C. W. (2006). *Encyclopedia of South American aquatic insects: Odonata – Anisoptera*. Dordrecht: Springer.
- Heckman, C. W. (2010). *Encyclopedia of South American aquatic insects: Odonata – Zygoptera*. Washington, DC: Springer.
- Henle, K., Davies, K. F., Kleyer, M., Margules, C., & Settele, J. (2004). Predictors of species sensitivity to fragmentation. *Biodiversity Conservation*, 13, 207–251. doi:10.1023/B:BIOC.0000004319.91643.9e
- Hueck, K. (1972). *As florestas da América do Sul* (pp. 442–448). São Paulo: Polígono.
- INPE (Instituto Nacional de Pesquisas Espaciais). (2014). *Centro de Previsão de Tempo e Estudos Climáticos, Banco de Dados Meteorológicos. Ministério da Ciência e Tecnologia*. Retrieved from <http://bancodedados.cptec.inpe.br/>
- Jeanmougin, M., Leprieux, F., Loïs, G., & Clergeau, P. (2014). Fine-scale urbanization affects Odonata species diversity in ponds of a megacity (Paris, France). *Acta Oecologia*, 59, 26–34. doi:10.1016/j.actao.2014.05.008
- Juen, L., Oliveira Junior, J. M. B., Shimano, Y., Mendes, T. P., & Cabette, H. S. R. (2014). Composition and richness of Odonata (Insecta) in streams with different levels of conservation in a Cerrado-Amazonian Forest ecotone. *Acta Amazonica*, 44, 223–233. doi:10.1590/S0044-59672014000200008
- Kittel, R. N., & Engels, W. (2014). Diversity of damselflies (Odonata: Zygoptera) of the state of Rio Grande do Sul, Brazil, with four new records for the state. *Notulae odonatologicae*, 8, 49–55.
- Koch, K., Wagner, C., & Sahlén, G. (2014). Farmland versus forest: Comparing changes in Odonata species composition in western and eastern Sweden. *Insect Conservation and Diversity*, 7, 22–31. doi:10.1111/icad.12034
- Lencioni, F. A. A. (2006). *The damselflies of Brazil: An illustrated identification guide 2 – Coenagrionidae*. São Paulo: All Print Editora.
- Machado, A. B. M. (2001). Studies on neotropical protonuridae (Odonata, Zygoptera). *Revista Brasileira de Zoologia*, 21, 333–336. doi:10.1590/S0101-81752001000300021
- Machado, A. B. M. (2006). Three new species of *Heteragrion* Selys, from Brazil with redescription of the holotype of *H. dorsale* Selys (Odonata, Megapodagrionidae). *Revista Brasileira de Zoologia*, 23, 1062–1070. doi:10.1590/S0101-81752006000400012
- May, M. L. (1976). Thermoregulation and adaptation to temperature in dragonflies (Odonata: Anisoptera). *Ecological Monographs*, 46, 1–32. doi:10.2307/1942392
- Monteiro Júnior, C. S., Couceiro, R. S. M., Hamada, N., & Juen, L. (2013). Effect of vegetation removal for road building on richness and composition of Odonata communities in Amazonia, Brazil. *International Journal of Odonatology*, 16, 135–144. doi:10.1080/13887890.2013.764798
- Monteiro Júnior, C. S., Juen, L., & Hamada, N. (2014). Analysis of urban impacts on aquatic habitats in the central Amazon basin: Adult odonates as bioindicators of environmental quality. *Ecological Indicators*, 48, 303–311. doi:10.1016/j.ecolind.2014.08.021
- Múrria, C., Rugenski, A. T., Whiles, M. R., & Vogler, A. P. (2015). Long-term isolation and endemism of Neotropical aquatic insects limit the community responses to recent amphibian decline. *Diversity and Distribution*, 21, 938–949. doi:10.1111/ddi.12343
- Myers, N., Mittermeier, R. A., Mittermeier, C. G., Fonseca, G. A. B., & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature*, 403, 853–858. doi:10.1038/35002501
- Oertli, B. (2008). The use of dragonflies in the assessment and monitoring of aquatic habitats. In A. Córdoba-Aguilar (Ed.), *Dragonflies and damselflies: Model organisms for ecological and evolutionary research*, Oxford, UK: Oxford University Press.
- Quadros, F., & Pata Pillar, V. (2002). Transições de floresta-campo no Rio Grande do Sul. *Ciência & Ambiente*, 24, 109–118.



- Remsburg, A. J., & Turner, M. G. (2009). Aquatic and terrestrial drivers of dragonfly (Odonata) assemblages within and among north-temperate lakes. *Journal of North American Benthological Society*, 28, 44–56. doi:10.1899/08-004.1
- Renner, S., Périco, E., & Sahlén, G. (2016). List of odonates from the Floresta Nacional de São Francisco de Paula (FLONA - SFP), with two new distribution records for Rio Grande do Sul, Brazil. *Biota Neotropica*, 16, 1–7. doi:10.1590/1676-0611-BN-2015-0132
- Renner, S., Sahlén, G., & Périco, E. (2016). Testing dragonflies as species richness indicators in a fragmented subtropical Atlantic Forest environment. *Neotropical Entomology*, 45, 231–239. doi:10.1007/s13744-015-0355-9
- Ribeiro, M. C., Metzger, J. P., Martensen, A. C., Ponzoni, F. J., & Hirota, M. M. (2009). The Brazilian Atlantic Forest: How much is left, and how is the remaining forest distributed? Implications for conservation. *Biological Conservation*, 142, 1141–1153. doi:10.1016/j.biocon.2009.02.021
- Rith-Najarian, J. C. (1998). The influence of forest vegetation variables on the distribution and diversity of dragonflies in a northern Minnesota forest landscape: A preliminary study (Anisoptera). *Odonatologica*, 27, 335–351.
- Sahlén, G. (1999). The impact of forestry on dragonfly diversity in Central Sweden. *International Journal of Odonatology*, 2, 177–186.
- Sahlén, G. (2006). Specialists vs. generalists among dragonflies – the importance of forest environments to form diverse species pools. In A. C. Rivera (Ed.), *Forests and dragonflies* (pp. 153–179). Bulgaria: Pensoft Publishers.
- Sahlén, G., & Ekestubbe, K. (2001). Identification of dragonflies (Odonata) as indicators of general species richness in boreal forest lakes. *Biodiversity and Conservation*, 10, 673–690. doi:10.1023/A:1016681524097
- Samways, M. J. (2003). Threats to the tropical island dragonfly fauna (Odonata) of Mayotte, Comoro Archipelago. *Biodiversity and Conservation*, 12, 1785–1792. doi:10.1023/A:1024120505611
- Samways, M. J., & Sharatt, N. J. (2010). Recovery of endemic dragonflies after removal of invasive alien trees. *Conservation Biology*, 24, 267–277. doi:10.1111/j.1523-1739.2009.01427.x
- Samways, M. J., & Steytler, N. S. (1995). Dragonfly (Odonata) distribution patterns in urban and forest landscapes, and recommendations for riparian management. *Biological Conservation*, 78, 279–288. doi:10.1016/S0006-3207(96)00032-8
- Samways, M. J., & Taylor, S. (2004). Impacts of invasive alien plants on Red-Listed South African dragonflies (Odonata). *South African Journal of Science*, 100, 78–80.
- Scheffer, M., van Geest, G. J., Zimmer, K., Jeppesen, E., Søndergaard, M., Butler, M. G., De Meester, L. (2006). Small habitat size and isolation can promote species richness: Second order effects on biodiversity in shallow lakes and ponds. *Oikos*, 112, 227–231. doi:10.1111/j.0030-1299.2006.14145.x
- Sheil, D. (1999). Tropical forest diversity, environmental change and species augmentation: After the intermediate disturbance hypothesis. *Journal of Vegetation Science*, 10, 851–860.
- Sick, H. (1982). *Ornitologia Brasileira, Uma Introdução*. Brasília, BR: Editora UnB.
- Smith, J., Samways, M. J., & Taylor, S. (2007). Assessing riparian quality using two complementary sets of bioindicators. *Biodiversity and Conservation*, 16, 2695–2713. doi:10.1007/s10531-006-9081-2
- Stewart, D. A. B., & Samways, M. J. (1998). Conserving dragonfly (Odonata) assemblages relative to river dynamics in an African savanna game reserve. *Conservation Biology*, 12, 683–692.
- Suhling, F., Sahlén, G., Martens, A., Marais, E., & Schütte, C. (2006). Dragonfly assemblage composition and diversity in arid tropical environments: A case study from western Namibia. *Biodiversity and Conservation*, 15, 311–332. doi:10.1007/s10531-005-2007-6
- Suhonen, J., Korkeamäki, E., Salmela, J., & Kuitunen, M. (2014). Risk of local extinction of Odonata freshwater habitat generalists and specialists. *Conservation Biology*, 28, 783–789. doi:10.1111/cobi.12231
- Tabarelli, M., Aguiar, A. V., Ribeiro, M. C., Metzger, J. P., & Peres, C. A. (2010). Prospects for biodiversity conservation in the Atlantic Forest: Lessons from aging human-modified landscapes. *Biological Conservation*, 143, 2328–2340. doi:10.1016/j.biocon.2010.02.005
- Taguchi, Y., & Oono, Y. (2005). Relational patterns of gene expression via non-metric multidimensional scaling analysis. *Bioinformatics*, 21, 730–740. doi:10.1093/bioinformatics/bti067
- Thiere, G., Milenkowski, S., Lindgren, P., Sahlén, G., Berglund, O., & Weisner, S. E. B. (2009). Wetland creation in agricultural landscape: Biodiversity benefits on local and regional scales. *Biological Conservation*, 142, 964–973. doi:10.1016/j.biocon.2009.01.006
- Thomas, P. (2013). *Araucaria angustifolia: The IUCN Red List of Threatened Species. Version 2014.3*. Retrieved from <http://www.iucnredlist.org>
- Veloso, H. P., Rangel Filho, A. L. R., & Lima, J. C. A. (1998). *Classificação da vegetação brasileira, adaptada a um sistema universal*. Rio de Janeiro: IBGE.
- With, K. A., & Crist, T. O. (1995). Critical thresholds in species responses to landscape structure. *Ecology*, 76, 2446–2459.
- Wittwer, T., Sahlén, G., & Suhling, F. (2010). Does one community shape the other? Dragonflies and fish in Swedish lakes. *Insect Conservation and Diversity*, 3, 124–133. doi:10.1111/j.1752-4598.2010.00083.x